

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

SEVENTH QUARTERLY PROGRESS REPORT (COVERING OCTOBER THROUGH DECEMBER 1977)

on

ACCELERATED / ABBREVIATED TEST METHODS, STUDY 4 OF TASK 3 (ENCAPSULATION) OF THE LOW-COST SILICON SOLAR ARRAY PROJECT

JPL CONTRACT NO. 954458

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, under NASA Contract NAS7-100 for the U.S. Energy Research and Development Administration, Division of Solar Energy.

The JPL Low-Cost Silicon Solar Array Project is funded by ERDA and forms part of the ERDA Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays.

Prepared January 3, 1978

by

J. M. Kolyer, Principal Investigator

N. R. Mann, Statistician



Rockwell International

Autonetics Strategic Systems Division
Electronic Systems Group
3370 Miraloma Avenue
P.O. Box 3105
Anaheim, California 92803



(NASA-CR-157087) ACCELERATED/ABBREVIATED
TEST METHODS, STUDY 4 OF TASK 3
(ENCAPSULATION) OF THE LOW-COST SILICON
SOLAR ARRAY PROJECT Quarterly Progress
(Rockwell International Corp., Anaheim,

N78-24632

Unclas
G3/44 20684

Autonetics Strategic Systems Division
Electronic Systems Group
3370 Miraloma Avenue
P.O. Box 4192
Anaheim, CA 92803



Rockwell
International

SEVENTH QUARTERLY PROGRESS REPORT
(Covering October through December 1977)
on
ACCELERATED/ABBREVIATED TEST METHODS,
STUDY 4 OF TASK 3 (ENCAPSULATION) OF THE
LOW-COST SILICON SOLAR ARRAY PROJECT

JPL CONTRACT NO. 954458

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, under NASA Contract NAS7-100 for the U.S. Energy Research and Development Administration, Division of Solar Energy.

The JPL Low-Cost Silicon Solar Array Project is funded by ERDA and forms part of the ERDA Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays.

Prepared January 3, 1978

by

J. M. Kolyer, Principal Investigator

and

N. R. Mann, Statistician

TABLE OF CONTENTS

	<u>Page</u>
I. SUMMARY	1
II. INTRODUCTION	2
III. DISCUSSION OF RESULTS THIS QUARTER	2
A. First Year Study (Inherent Weatherability of Transparent Encapsulants)	2
1. Transparent Plastic Films	2
2. Universal Test Specimens (UTS's)	3
B. Second Year Study	4
1. Inherent Weatherability of UTS's with Nine Different Encapsulant-Substrate Combinations	4
2. Hyperacceleration by the UV Component of Highly-Concentrated Natural Sunlight	5
IV. CONCLUSIONS AND RECOMMENDATIONS	5
V. PLANS FOR NEXT QUARTER	6
A. First Year Study	6
B. Second Year Study	6
VI. REFERENCES	6

LIST OF FIGURES

	<u>Page</u>
1. Yellowing of Lexan in Phoenix (45°S)	7
2. Yellowing of Lexan in Miami (45°S)	8

LIST OF TABLES

	<u>Page</u>
I. Retention of Maximum Power by Solar Cells in UTS's Exposed Outdoors	9
II. Conditions for Accelerated Exposure of UTS's with Nine Different Encapsulant-Substrate Combinations	10
III. Electrical Data on Moisture-Degraded Solar Cells (after 72 days at 80°C and 100% Relative Humidity)	11
IV. Conditions for Exposures Planned with the Solar Furnace	12
V. Transmission of Schott UG-11 UV-Transmitting Black Glass, 3 mm Thick	13

I. SUMMARY

To meet the goals of the LSSA program, solar cell encapsulants must provide protection for 20 years. Consequently, the objective of the present program is to develop methodology for making confident predictions of encapsulant performance at any exposure site in the U.S.A.

During the first year of the program, inherent weatherability was studied. Inherent weatherability is controlled by the three weather factors common to all exposure sites: insolation, temperature, and humidity. Emphasis was focused on the transparent encapsulant portion of miniature solar cell arrays by eliminating weathering effects on the substrate and circuitry (which are also parts of the encapsulant system). The most extensive data were for yellowing, which was measured conveniently and precisely. Considerable data also was obtained on tensile strength. Changes in these two properties after outdoor exposure were predicted very well from accelerated exposure data. This is remarkable considering that outdoor UV intensity data is very limited. In addition, the feasibility of predicting an important but difficultly-measured property by correlation with an easily-measured property was demonstrated. Although more outdoor exposure data will be received, this first part of the program can be said to be successfully concluded.

In continuation of the study, the power output of solar cells is being monitored in accelerated test conditions and in outdoor exposures. For this purpose, Universal Test Specimens (UTS's) with nine different substrate/transparent encapsulant combinations were prepared. Again, the objective is to predict outdoor performance from accelerated exposure data with photochemical stresses of 8 times normal. Continuous accelerated exposure under 8 key combinations of ultraviolet (UV) light intensity, temperature, and humidity for 2 months has been completed. Solar cell performance, which degrades due to moisture, now will be forced to the failure point by exposure of the UTS's to 100 percent relative humidity at 100° C.

A subsequent objective is to accelerate degradation rates by a factor of 100 or more. This includes the purely thermal reactions, such as hydrolysis, as well as the photochemical reactions. The photochemical acceleration is the more difficult problem. The use of natural sunlight avoids the problem of imperfect matching of the solar spectrum by lamps. However, it must be established how much the UV component of sunlight can be concentrated on samples without changing the degradation mechanism. Exposure of plastic films is planned at the Army's solar furnace at White Sands in February 1978.

ORIGINAL PAGE IS
OF POOR QUALITY

II. INTRODUCTION

The first year study (inherent weatherability of transparent encapsulants) is nearing completion. Successful predictions for the rate of loss of properties on outdoor exposure were made for plastic films based upon accelerated data. These predictions were summarized in the last (Sixth) Quarterly Progress Report. Degradation data for samples exposed beginning in winter, summer, or fall are discussed below. The electrical performance of solar cells in UTS's exposed outdoors is also reported.

The second year study involves UTS's with several transparent encapsulant-substrate systems which are relatively rapidly degraded on outdoor exposure. The key property being followed is maximum power output of the solar cells. Exposure conditions and the status of the test program are discussed below.

Of special interest is the possibility of hyperacceleration of photochemical degradation, e.g., by 100 times, by exposing samples to the UV component of mirror-concentrated sunlight in a solar furnace. Plans for a trial of this principle are described.

III. DISCUSSION OF RESULTS THIS QUARTER

A. First Year Study (Inherent Weatherability of Transparent Encapsulants)

1. Transparent Plastic Films

Data are complete for yellowness (optical absorbance at 360 nm) and tensile strength of plastic films exposed outdoors for up to 300 days. Electrical properties of similarly-exposed Universal Test Specimens (UTS's) also have been determined. All of these results are tabulated in the Interim Report, prepared on October 24, 1977.

Data from 24-condition accelerated exposure were correlated successfully with abbreviated (outdoor) data. Predictions are summarized in the Sixth Quarterly Progress Report (for July through September 1977), and full details of the mathematical procedures were presented to JPL in a letter of October 21, 1977.

Outdoor exposure of Lexan and polystyrene films was initiated in the fall of 1976. These samples are now deteriorating badly. In Miami, polystyrene exposed at 45°S for 300 days (started 10-20-76) was so badly embrittled that the test was terminated. The same was true for Lexan at 379 days (exposure started 9-1-76) or 340 days (exposure started 12-22-76). In Phoenix, EMMAQUA exposure of Lexan ended due to embrittlement at 300 days and EMMA exposure ended at 420 days.

Interest now centers on the relative rates of degradation of Lexan exposed beginning in fall or on the winter and summer solstices. Degradation rates are much higher in summer than in winter because of greater UV intensity. Therefore, seasonal data are necessary to refine our mathematical models.

Outdoor exposure of Lexan film samples at 45°S (tilted 45°, facing south) was begun in Phoenix and Miami on the winter and summer solstices (December 22, 1976 and June 21, 1977) to obtain seasonal values for model equation parameters. Data are complete for the absorbance of these films at 360 nanometers: up to 300 days exposure for those started on the winter solstice and 150 days for those started on the summer solstice. Results are shown graphically in Figures 1 and 2.

The "exposure factor" is based upon temperature levels experienced by the samples and, more importantly, the cumulative ultraviolet light energy received. Several assumptions were necessary in calculating the exposure factor. These are given, along with monthly values for the factor at Phoenix and Miami, in the letter of October 21, 1977 from J. M. Kolyer to H. E. Marsh of JPL.

There appears to be a tendency for the absorbance values to converge after about 300 days whether exposure began in fall, midsummer, or midwinter. The data points of a Weibull plot in general suggest an exponential model (slope = 1), but a rigorous analysis remains to be made. An exponential model is attractive because it represents a simple photochemical reaction. However, some other model, such as the lognormal, may eventually give the best fit.

2. Universal Test Specimens (UTS's)

Power loss of the solar cells in the silicone rubber-encapsulated UTS's of the first year study was attributed to moisture-induced lifting of the contacts (grid lines) from the silicon surface (Reference 1). Degradation was severe (average retention of original power for the six cells of a UTS = 57 percent) after exposure in the dark at 80°C and 100 percent relative humidity for 72 days. Table I shows that at 300 days the cells in UTS's exposed outdoors also have shown significant power loss, especially in Miami (natural exposure tilted at 45° facing south) and in Phoenix on the EMMA sunlight-concentrator. Faster degradation in Miami than Phoenix was expected because of Miami's moist climate. However, EMMAQUA exposure, in which samples are sprayed with water 8 minutes each hour, would have been expected to be more severe than EMMA exposure, which involves no spraying. The UTS's exposed outdoors for 420 days now have been returned from the test sites but must be electrically tested by the solar cell manufacturer.

B. Second Year Study

1. Inherent Weatherability of UTS's with Nine Different Encapsulant-Substrate Combinations

The nine array systems are described in our Sixth Quarterly Progress Report.

Outdoor exposure of UTS's began at Florida (45°S) on October 31, 1977 and at Phoenix (45°S, EMMA, EMMAQUA) on October 23, 1977.

Accelerated (xenon lamp) exposure was continued for 61 days. The eight exposure conditions are given in Table II. The property monitored was current (in milliamperes) produced by the solar cells at 0.350 volts. The "power point", which is that point on the IV curve at which the product of current and voltage is at a maximum, occurs for our solar cells in the vicinity of 0.350 volts. Therefore, current at 0.350 volts is a good relative measure of the maximum power produced by the cell. That this statement is true was demonstrated by examining IV curve data obtained by Optical Coating Laboratory, Inc. on solar cells before and after moisture-induced degradation of the contacts. Table III shows that the percent of original power calculated from data for current at 0.350 volts is very close to that found from the actual power point data.

The measurement of a single point on the IV curve without locating the exact power point simplified the experimental procedure so that we could obtain several exposure time points for mathematical modeling. Tape cables from the UTS's in the xenon lamp cabinet were successively plugged, by means of an edge connector, into a rotary switch, allowing convenient measurement of the six solar cells on each UTS. All data were expressed in terms of a reference cell at a fixed distance from the lamp.

For UTS's exposed outdoors, both milliwatts at the power point and milliamperes at 0.350 volts will be monitored.

As done previously for plastic film properties, solar cell performance after outdoor exposure will be predicted on the basis of accelerated data. Also, observation of failure modes will be of special interest because the array systems were designed with several possible "weak links".

A difficulty is that the cells used in this test, unlike the cells attached to the earlier (silicone rubber encapsulated) UTS's, have a uniform coating of solder on the Ti-Ag grid lines (contacts). Therefore, moisture penetration will take considerably longer. It is moisture penetration that causes hydrogen evolution by the Ti-Ag couple, with accompanying separation at the Ti-Si interface. The result is lifting of the contacts and decreased power (Reference 1).

The current at 0.350 volts for each of the 144 solar cells in the accelerated exposure (6 cells on each of 24 UTS's) was determined after 0, 2, 5, 9, 19, 40 and 61 days exposure. Results are being calculated and will be given in the January 1978 Monthly Progress Report. Observations on encapsulant degradation also will be reported. To accelerate failure by moisture-induced degradation of the contacts, which are relatively resistant in this test as mentioned above, UTS's now are being exposed to steam at 100°C. Resulting data will indicate whether or not ionic degradation products from the deteriorated encapsulants can accelerate corrosion of the solar cell contacts.

2. Hyperacceleration by the UV Component of Highly-Concentrated Natural Sunlight

Experimental work is planned for the week of February 13, 1978 at the Army's solar furnace at White Sands, New Mexico.

It is planned to expose polystyrene and Lexan films, along with novel actinometer films provided by A. Gupta of JPL. Conditions are listed in Table IV.

The visible/infrared regions of the solar spectrum must be removed to avoid overheating the samples. Schott UV-transmitting black glass filters have been purchased for this purpose. The transmission at several wavelengths was checked and found to be close to typical values given by the manufacturer (Table V).

At White Sands, it is planned to cool the heat shock-sensitive Schott glass with flowing water. However, if this glass should break, an aqueous solution of nickelous and cobaltous sulfates (Reference 2) in a Vycor cell will be used as the filter.

The objective is to obtain precise data on absorbance at 360 nm for the films which will make possible graphical plots. These plots will disclose the intensity level at which the mathematical model for degradation changes. This level will be the upper limit at which the hyperaccelerated method represents normal exposure.

IV. CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions regarding prediction of outdoor exposure data from accelerated exposure data were given in the last (Sixth) Quarterly Report. These conclusions were drawn from the first year study on inherent weatherability of transparent encapsulants. The second year study is in progress and no conclusions are possible at this point.
2. It is recommended that multicondition exposure, as used successfully in the predictions of the first year study, be applied in the final evaluation of candidate encapsulants. Relatively precise lifetime prediction will be required to single out the most cost-effective materials.

V. PLANS FOR NEXT QUARTER

A. First Year Study

1. Continue to monitor outdoor exposures of UTS's and plastic films. Estimate seasonal degradation rates and refine mathematical models.
2. Examine weathered Tedlar and polystyrene films by Fourier transform attenuated total reflectance (ATR) infrared spectroscopy. The quantification of subtle changes in a weather-resistant plastic such as Tedlar is essential to prediction of its lifetime.

B. Second Year Study

1. Monitor the maximum power of solar cells on UTS's exposed to steam at 100°C in the accelerated test. Also monitor maximum power of solar cells in UTS's exposed outdoors. Predict retention of power output by the cells on UTS's exposed outdoors from the accelerated power data. Determine whether corrosive products from encapsulant degradation accelerate the rate of moisture attack on metallization (grid lines) on the cell.
2. Expose plastic films to the UV component of sunlight at high concentrations using the Army's solar furnace at White Sands, New Mexico. By mathematical modeling of data, determine the upper light intensity limit at which the degradation mechanism remains unchanged and normal exposure is validly represented. If successful, this technique could be of wide application in the testing of materials such as plastics and coatings.

VI. REFERENCES

1. Interim Report, This Contract (JPL Contract No. 954458), October 24, 1977, page 10.
2. L. R. Koller, Ultraviolet Radiation, Second Edition, Wiley and Sons, 1965, page 174.

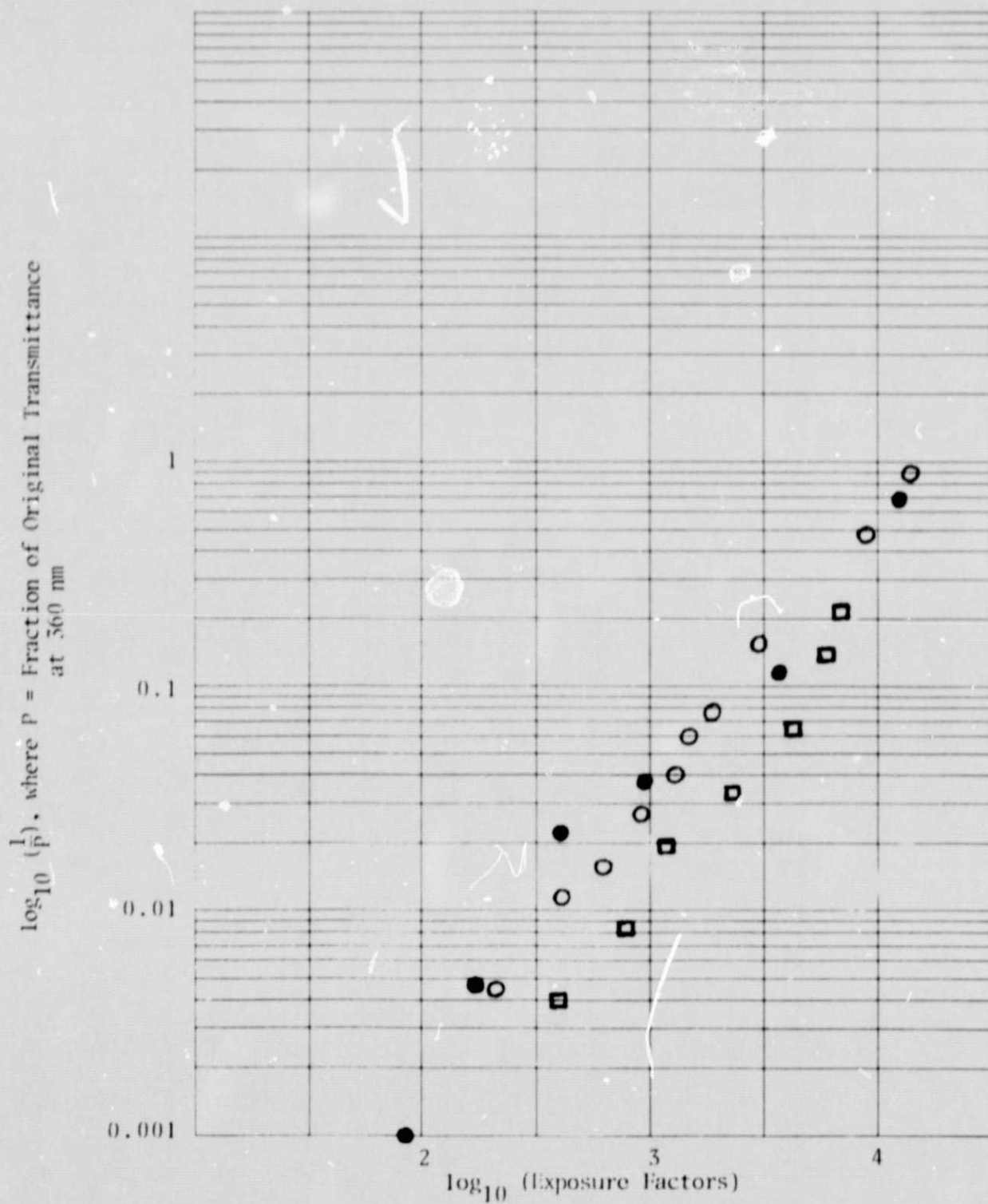


Figure 1. Yellowing of Lexan in Phoenix (45°S)

- Exposure started 9/12/76
- Exposure started 12/22/76
- Exposure started 6/21/77

**ORIGINAL PAGE IS
OF POOR QUALITY**

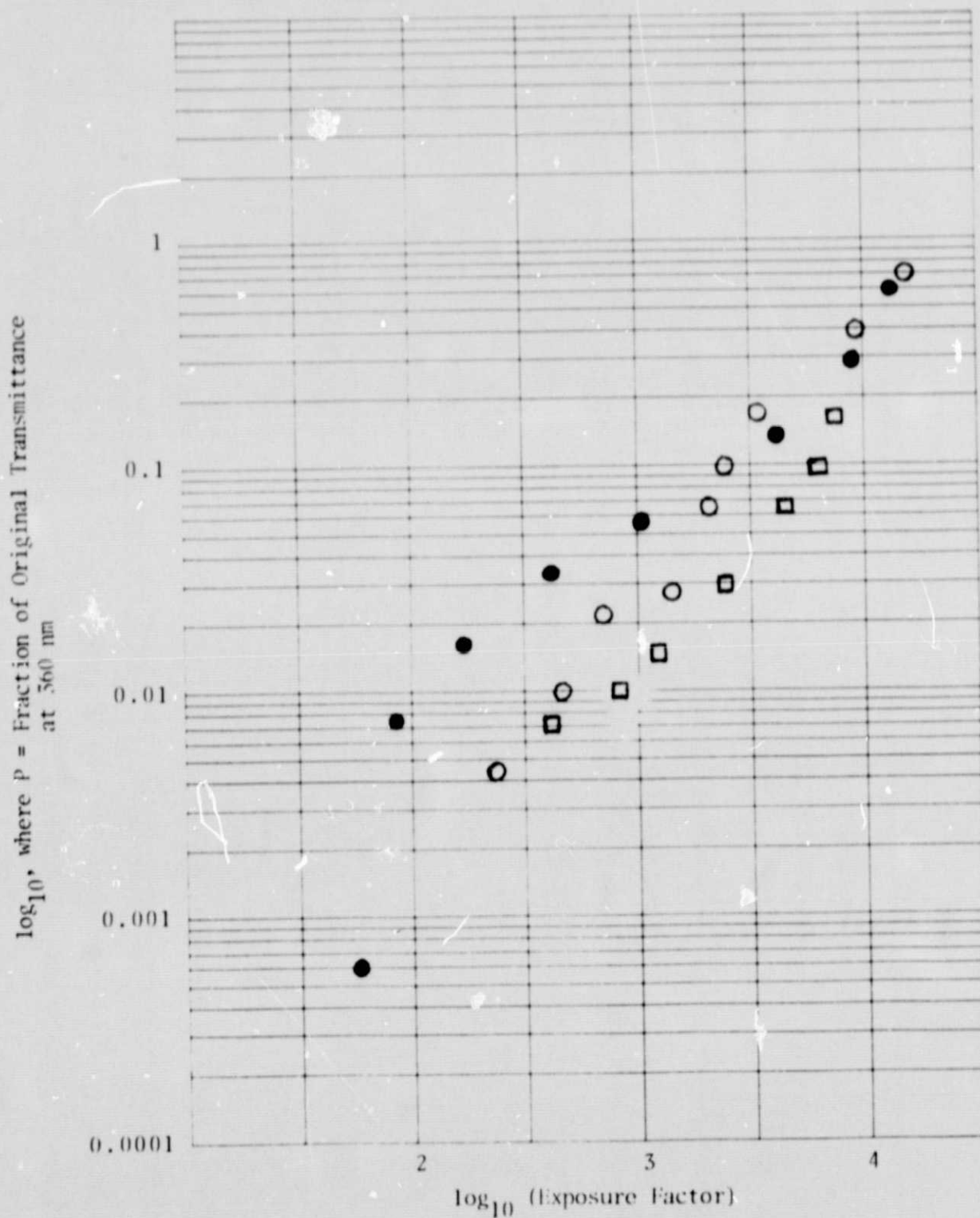


Figure 2. Yellowing of Lexan in Miami (45°S)

- Exposure started 9/1/76
- Exposure started 12/12/76
- Exposure started 6/21/77

TABLE I
Retention of Maximum Power by Solar Cells
in UTS's Exposed Outdoors

Exposure Time, Days	Miami, 45°S	Phoenix, 45°S	EMMA	EMMAQUA
5	100	103	101	97
10	100	108	99	101
15	97	102	-	-
30	98	103	95	100
60	93	87	-	-
90	99	90	100	97
150	99	94	97	99
210	85	90	88	96
300	78	95	83	92

TABLE II
Conditions for Accelerated Exposure
of UTS's with Nine Different
Encapsulant-Substrate Combinations

Condition No.	UV Intensity Relative to Noon Summer Sunlight	Encapsulant Temperature, °C	Relative Humidity, %
1	0.66	28	100
2	1.00	43	0
3	1.00	43	100
4	1.00	72	0
5	1.00	72	100
6	0.66	64	100
7	0	72	0
8	0	72	100

**ORIGINAL PAGE IS
OF POOR QUALITY**

TABLE III

Electrical Data on Moisture-Degraded Solar Cells
(After 72 Days at 80°C and 100% Relative Humidity)

Cell No.	Power Point, milliwatts		Power Point After Exposure, % of Original
	Original	After Exposure	
1	17.7	9.33	53
2	17.7	9.98	56
3	17.9	7.38	41
4	17.4	15.4	89
5	15.1	6.92	46
6	18.7	8.72	47
Cell No.	Current, milliamperes, at 0.350 volts		Current at 0.350 volts After Exposure, % of Original
	Original	After Exposure	
1	50.5	25.7	51
2	51.0	28.4	56
3	50.5	20.7	41
4	49.4	42.8	87
5	42.3	18.3	43
6	54.3	23.5	43

TABLE IV
Conditions for Exposures Planned
with the Solar Furnace

Sunlight Concentration, suns*	Exposure Time, hours
25	0.2, 0.4, 0.8, 1.6, 3.2
50	"
100	"
200	"
300 - 400	"

*A filter will transmit only the UV component to prevent overheating of samples by visible/infrared light.

TABLE V

Transmission of Schott UG-11
UV-Transmitting Black Glass, 3 mm Thick

Wavelength, nm	Percent External Transmission	
	Schott's Data, Typical	Found for Melt No. 745922
300	65	68
320	73	74
360	63	61
500	<0.001	0.1
800	0.001	0.2
1000	<0.001	-